Applied Fluid Mechanics

Chapter 6

Flow of Fluids and Bernoulli's Equation

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So far in this course, the fluid has been completely static. Now the fluid will begin to move. Designing dynamic fluid systems requires an understanding of engineering principles presented in the remainder of the book.

Source: Ilya Postnikov/123RF

Quantifying Flow Rates

Q The *volume flow rate* is the volume of fluid flowing past a section per unit time.

W The *weight flow rate* is the weight of fluid flowing past a section per unit time.

M The *mass flow rate* is the mass of fluid flowing past a section per unit time.

Flow Rate Calculations and Units

Symbol	Name	Definition	SI Units	U.S. Customary System Units
Q	Volume flow rate	$Q = Av$	m^3/s	ft^3/s
W	Weight flow rate	$W = \gamma Q$	N/s	lb/s
		$W = \gamma A v$		
M	Mass flow rate	$M = \rho Q$	kg/s	slugs/s
		$M = \rho A v$		

Pearson

Continuity Equation – based on the Conservation of Mass

$$M_1 = M_2$$

$$M = \rho A v$$

Continuity Equation for Any Fluid

$$\rho_1 A_1 v_1 = \rho_2 A_2 v_2$$

Since liquids are incompressible, having constant density, cancel rho on both sides of the equation

- **Continuity equation for liquids**

$$A_1 v_1 = A_2 v_2$$

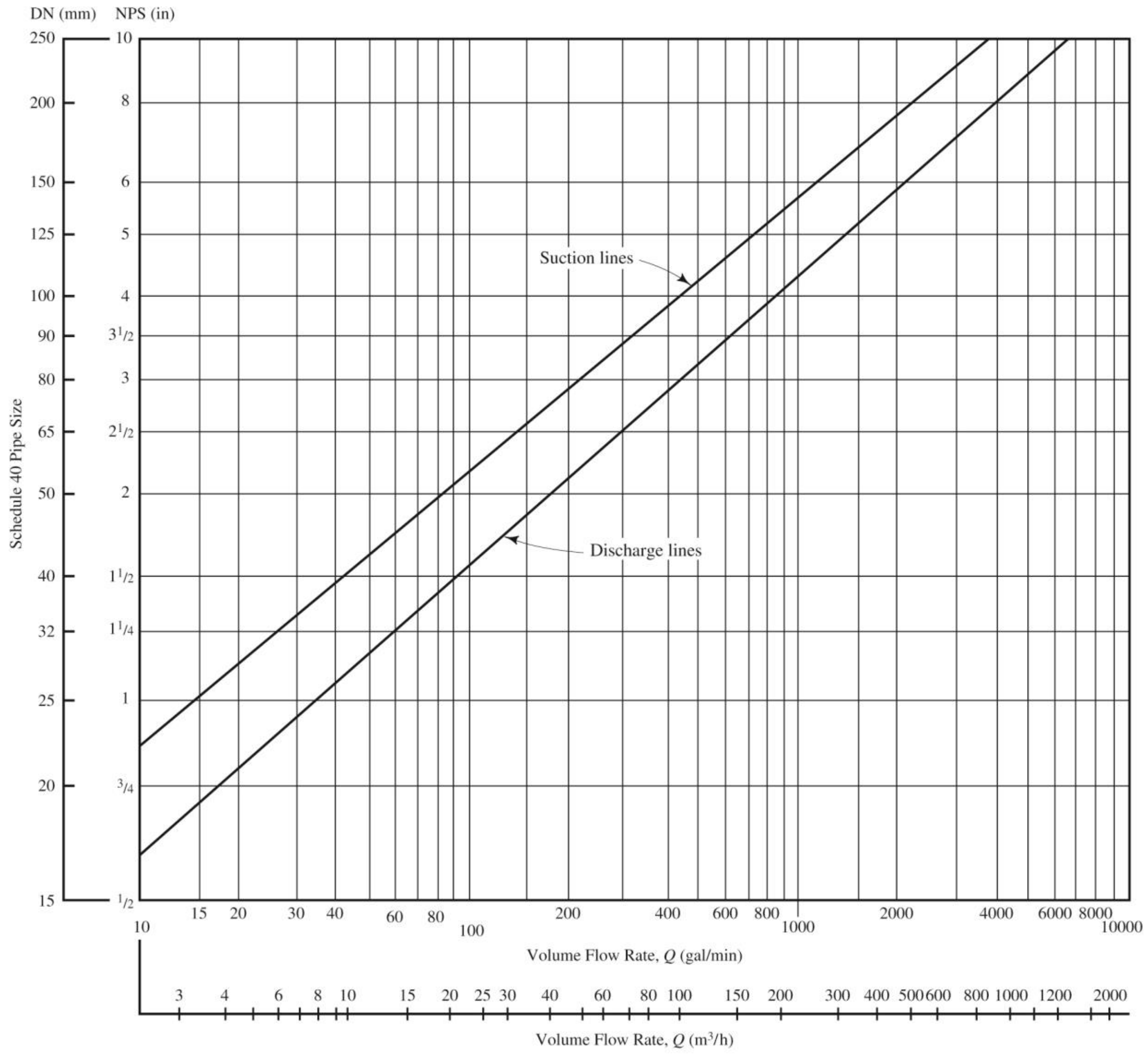
or, because $Q = Av$, we have

$$Q_1 = Q_2$$

Commercially Available Pipe and Tubing

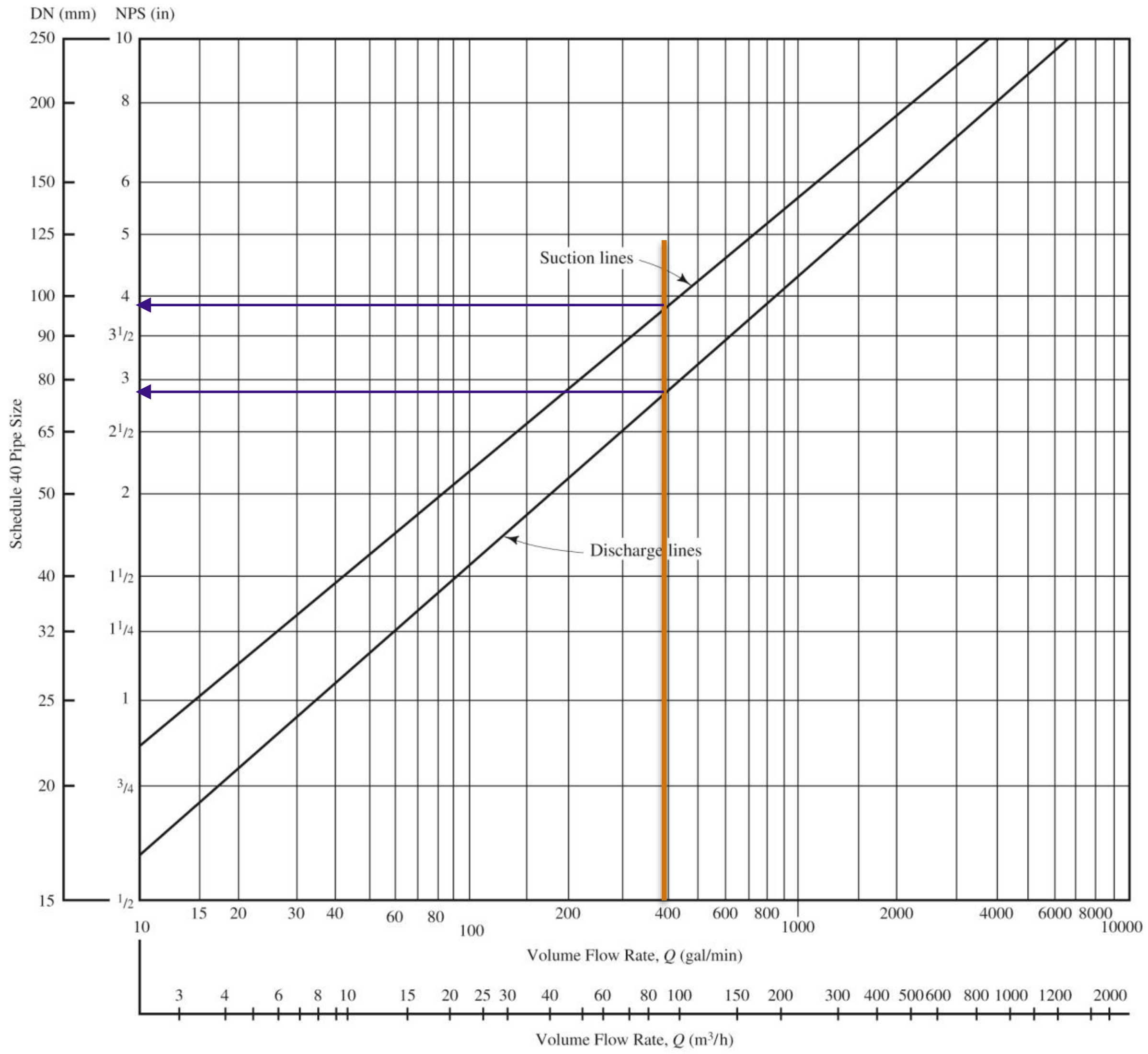
- Designer should always be aware of standard commercial components in their fields to reduce cost, speed construction, improve serviceability, and offer compatibility with other designs.
- Take time to familiarize yourself with the components in the appendix of this book. The standards in this appendix will serve you throughout your career, anywhere in the world.
- Included in the appendix
  - Steel pipe
  - Steel tubing
  - Copper tubing
  - Ductile iron pipe
  - Plastic pipe and tubing
  - Hydraulic hose

Pipe-size selection aid (quick estimate)



Pearson

Pipe-size selection aid (quick estimate)



Conservation of Energy Bernoulli's Equation

- If energy is neither created nor destroyed, then two points in a flow system can set the value of total energy at each point to be the same.
- Many fluid systems consider three forms of energy:
  - Potential Energy – held by a fluid due to its elevation
  - Kinetic Energy – held by a fluid due to its velocity
  - Flow Energy – (*pressure energy* or *flow work*) the amount of work necessary to move the fluid across the section against the pressure

Bernoulli’s Equation (cont.)

$$E = \text{FE} + \text{PE} + \text{KE}$$

$$E = wp/\gamma + wz + wv^2/2g$$

So, for two points in the system then,

$$E_1 = E_2$$

$$\frac{wp_1}{\gamma} + wz_1 + \frac{wv_1^2}{2g} = \frac{wp_2}{\gamma} + wz_2 + \frac{wv_2^2}{2g}$$

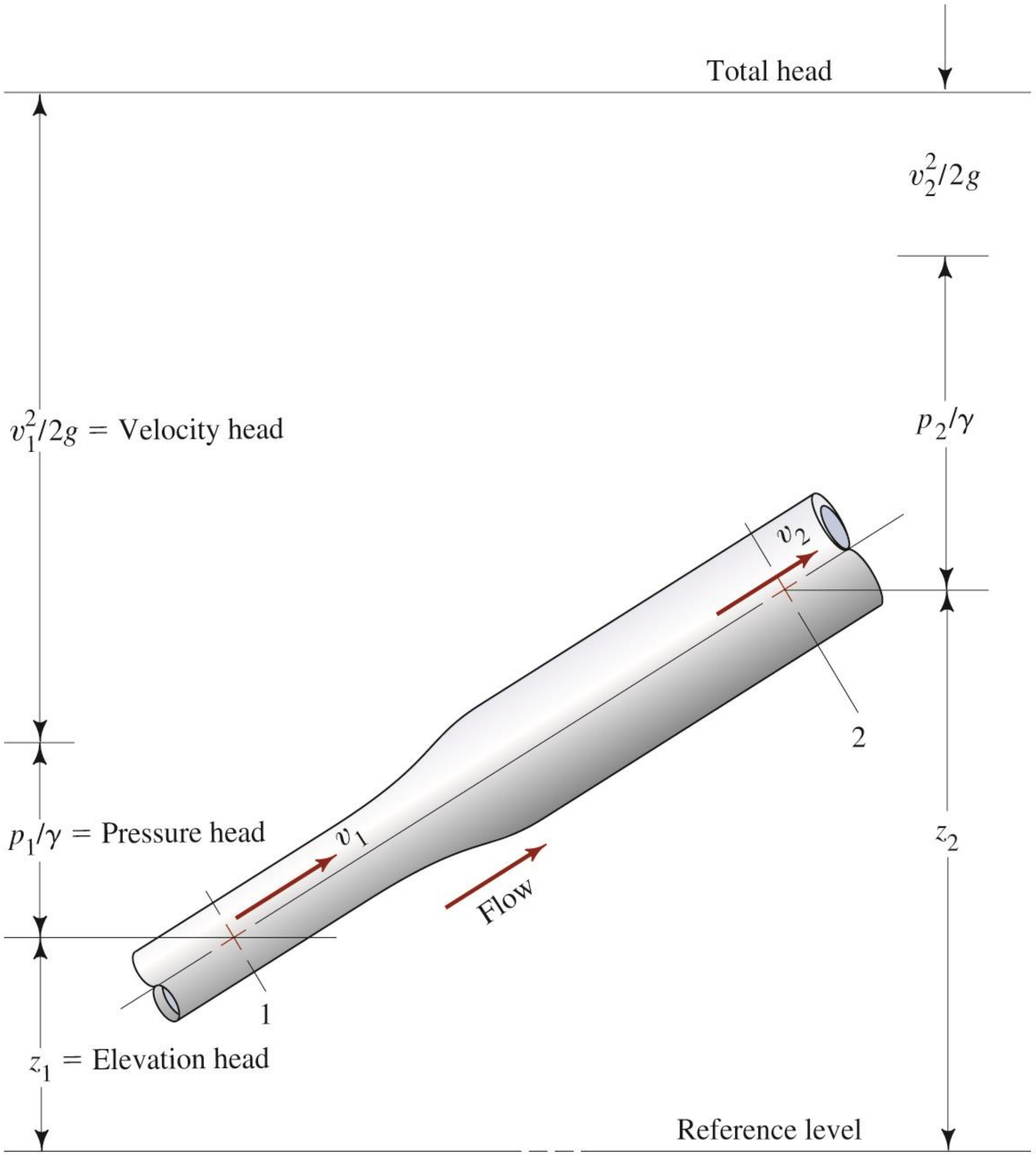
The Conservation of Energy applied to two points, with no energy added, lost, or removed:

Bernoulli's Equation

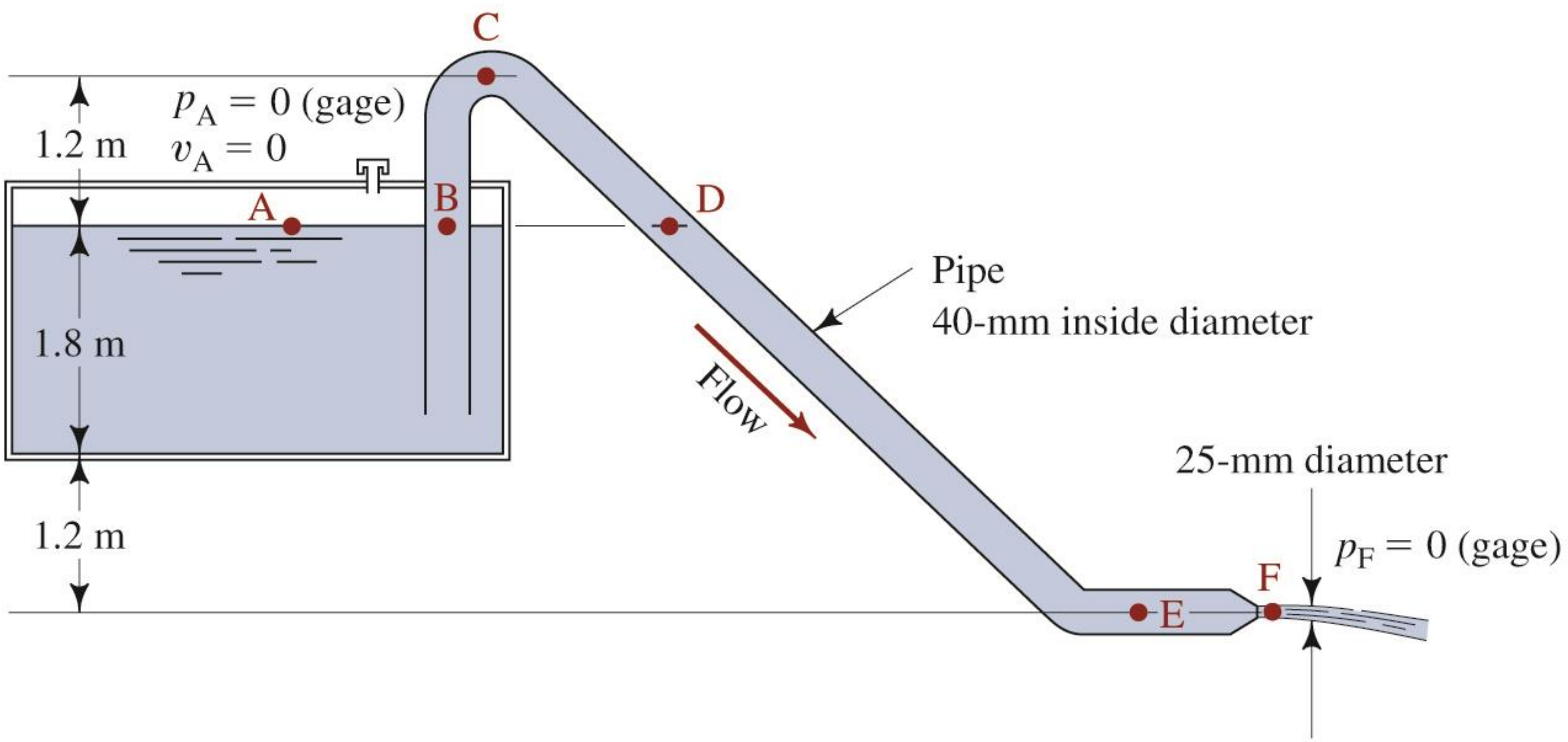
$$\frac{p_1}{\gamma} + z_1 + \frac{v_1^2}{2g} = \frac{p_2}{\gamma} + z_2 + \frac{v_2^2}{2g}$$

Note that the terms in Bernoulli's Equation are all "head" terms, meaning that they represent the energy held per *unit weight of fluid*.

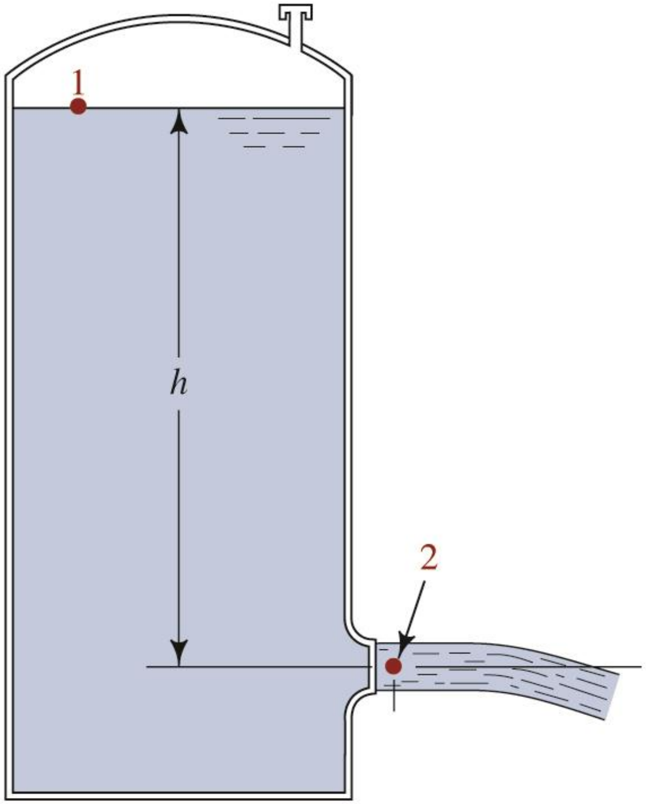
Pressure head, elevation head, velocity head, and total head



Siphon for Example Problem 6.10



Since the elevation head is constantly changing as the tank below drains, Torricelli's Theorem can be applied to account for the variation of height, and hence flow rate, over time.



➩ Torricelli's Theorem

$$v_2 = \sqrt{2gh}$$

Flow due to a falling head

➪ Time Required to Drain a Tank

$$t_2 - t_1 = \frac{2(A_t/A_j)}{\sqrt{2g}}\left(h_1^{1/2} - h_2^{1/2}\right)$$

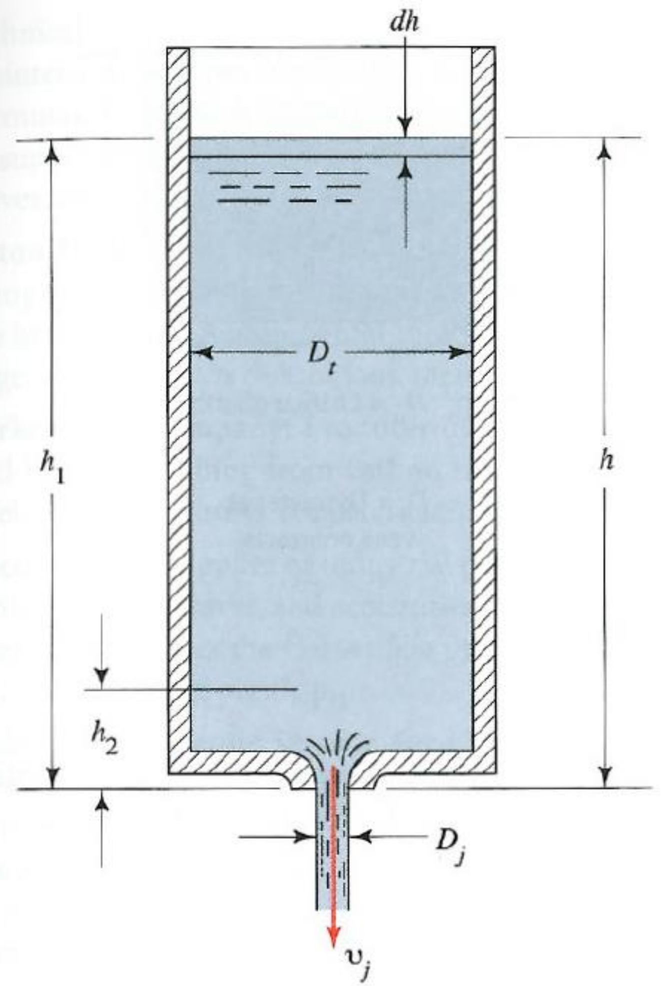
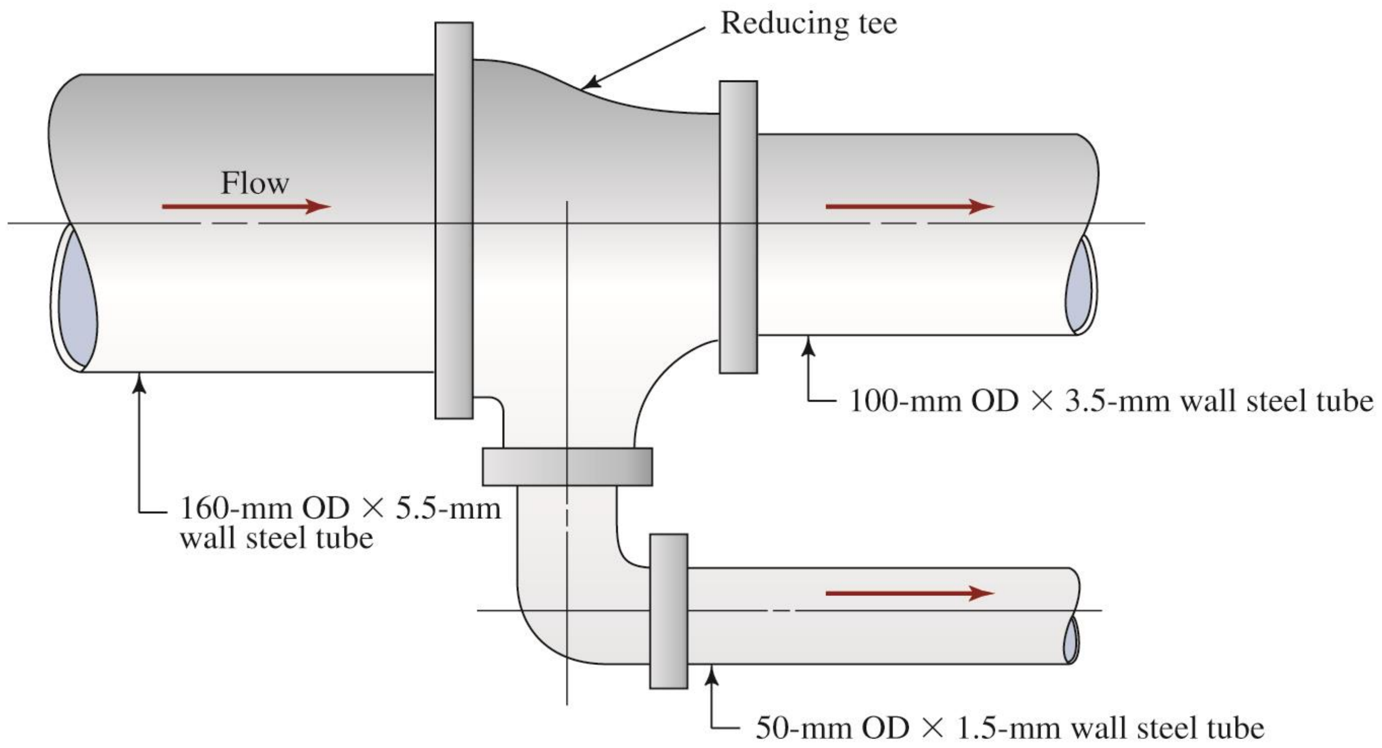
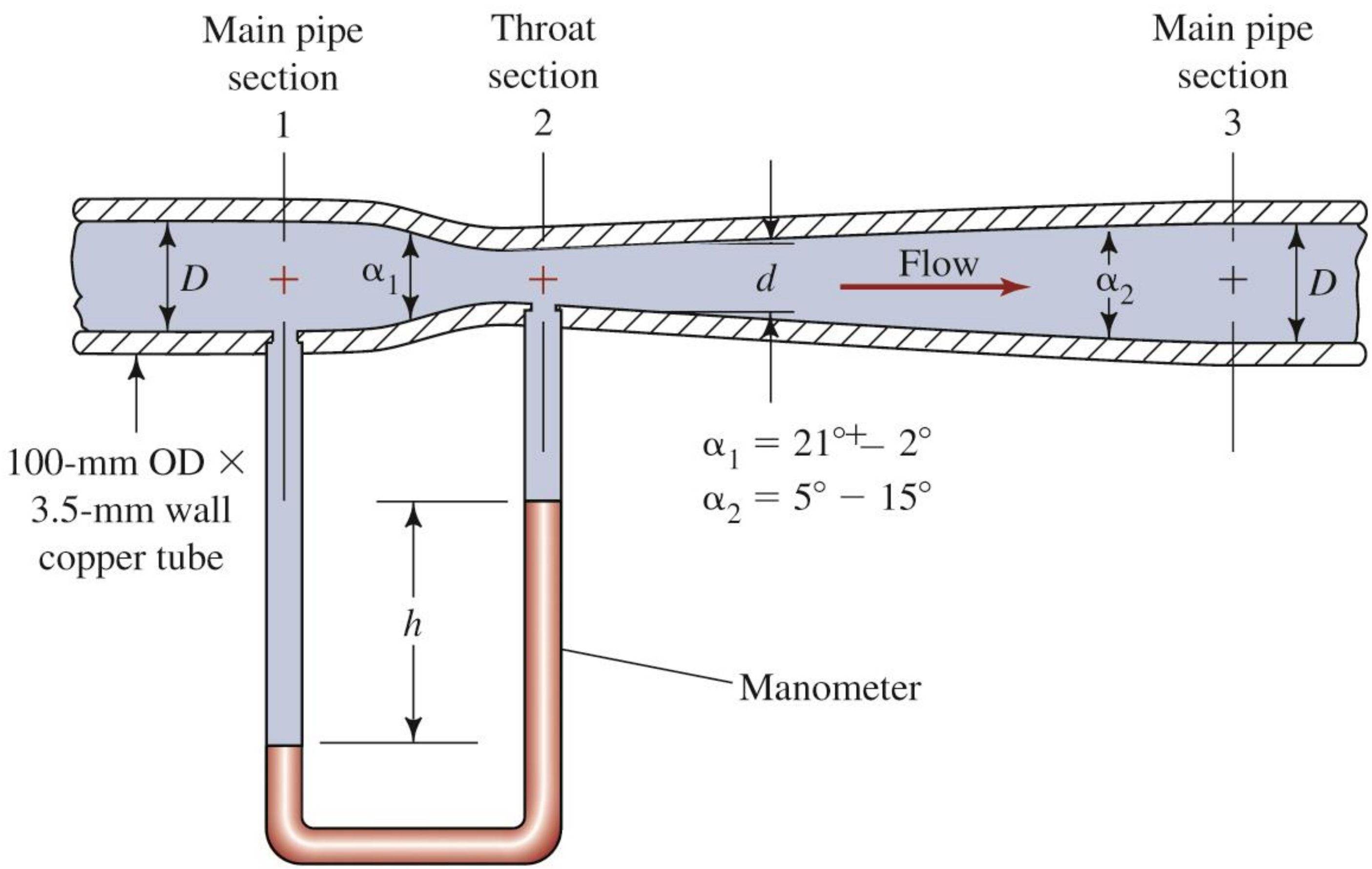


FIGURE 6.14 Flow from a tank with falling head. Also for Problems 6.95–6.106.

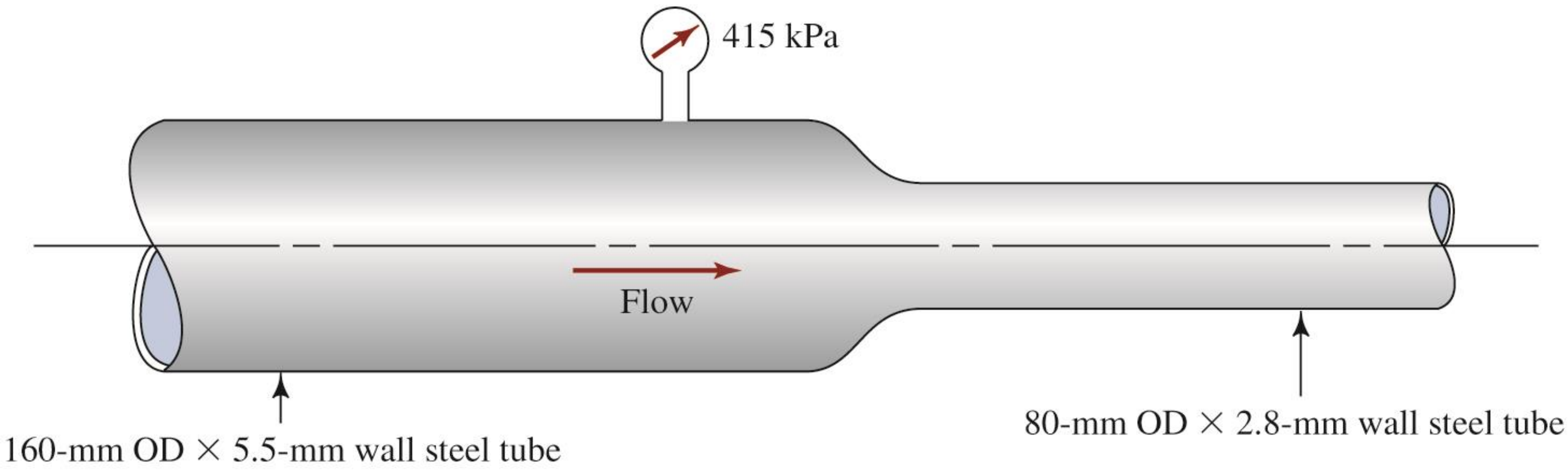
Apply the Continuity Equation and your knowledge of the appendix data to solve Problem 6.41



Venturi meter for Problem 6.58

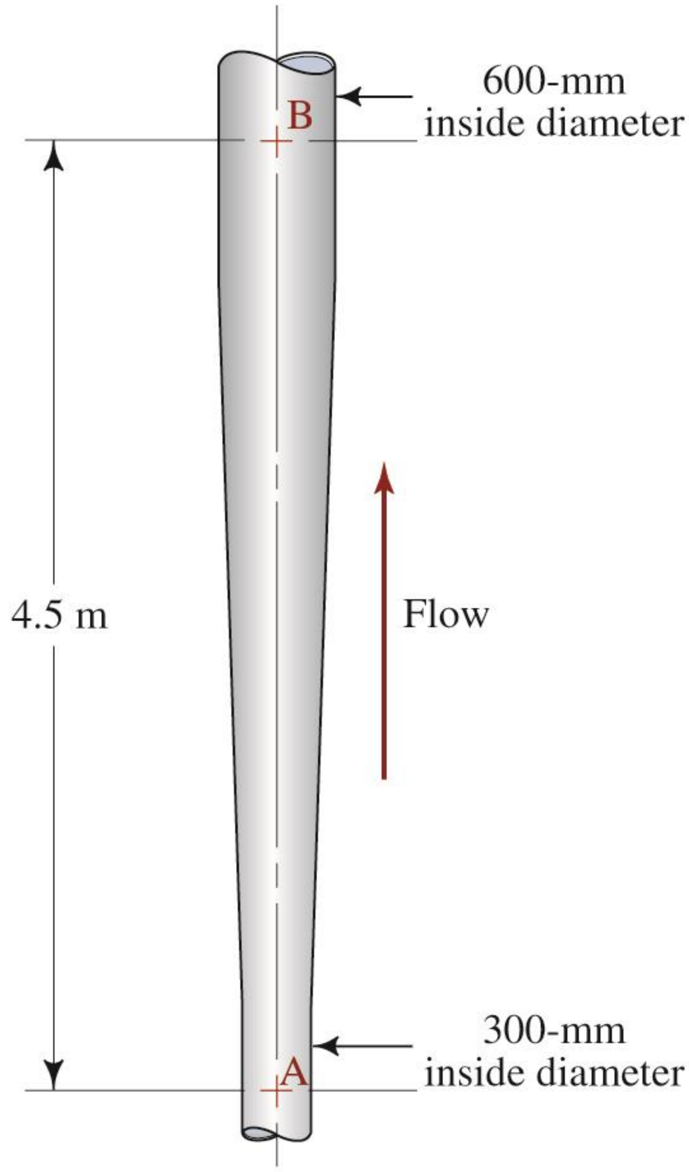


Fabricated tube for Problem 6.60

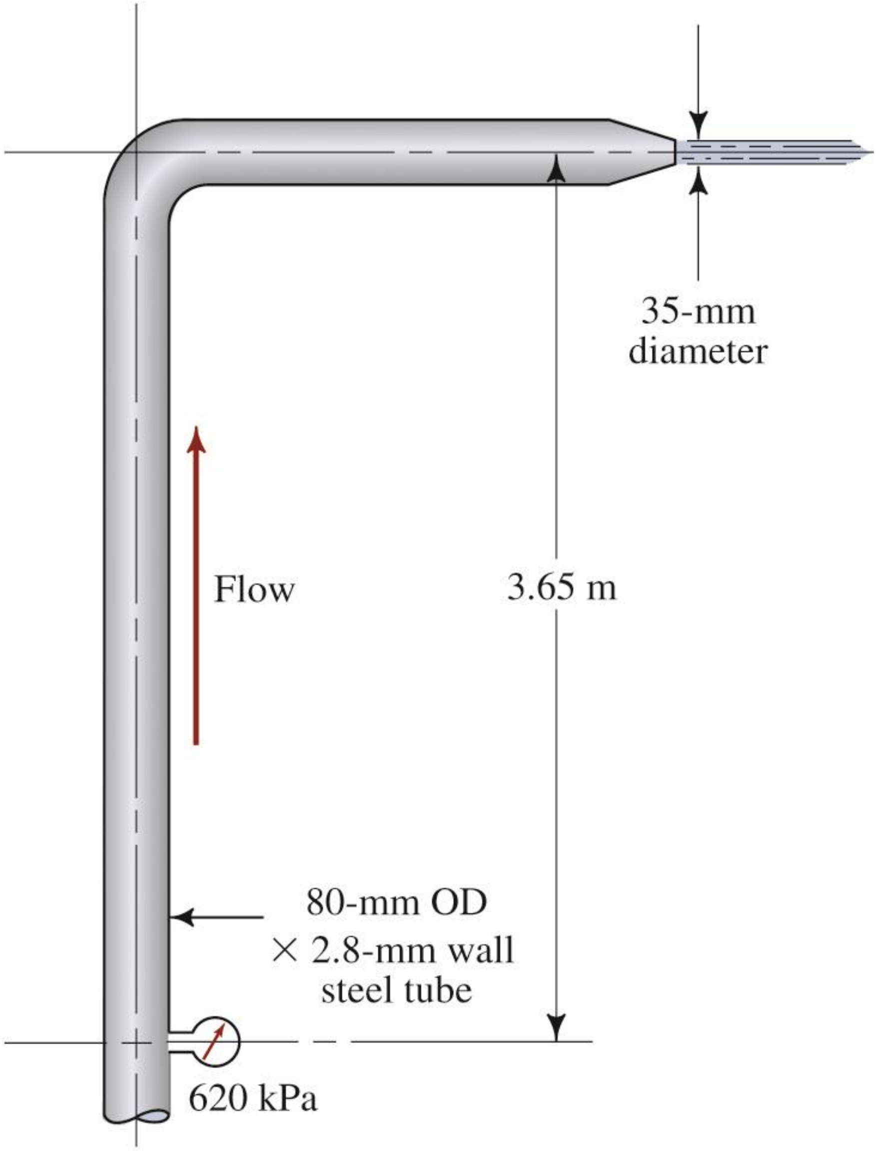


Pearson

Expanding tube for Problem 6.61

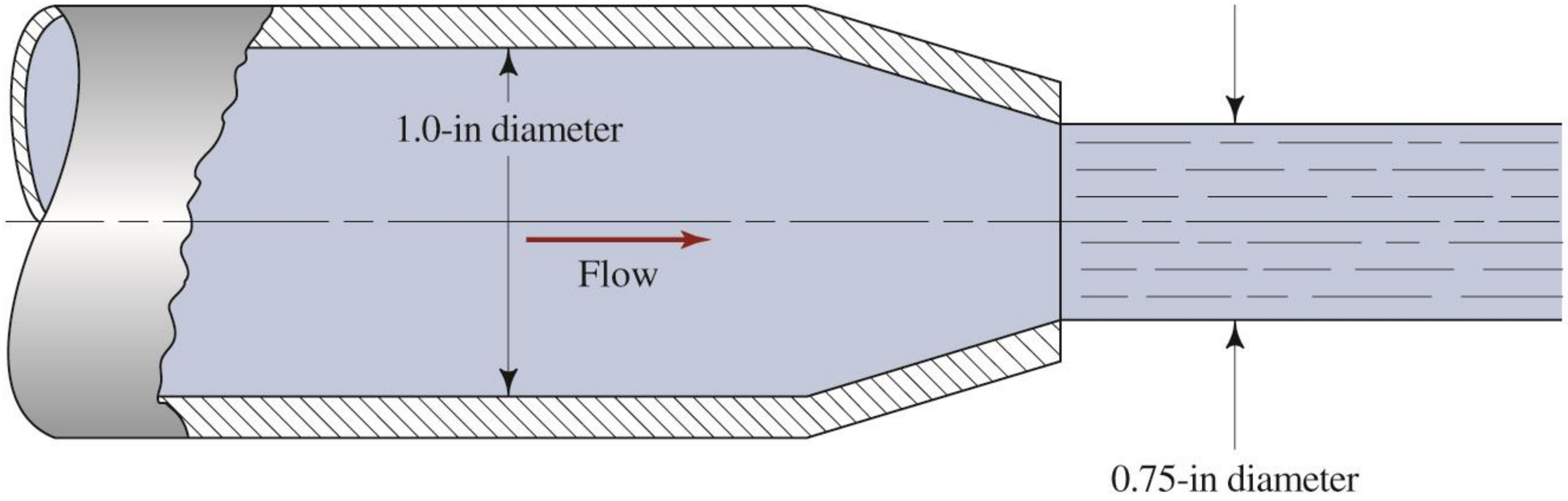


System for Problem 6.62

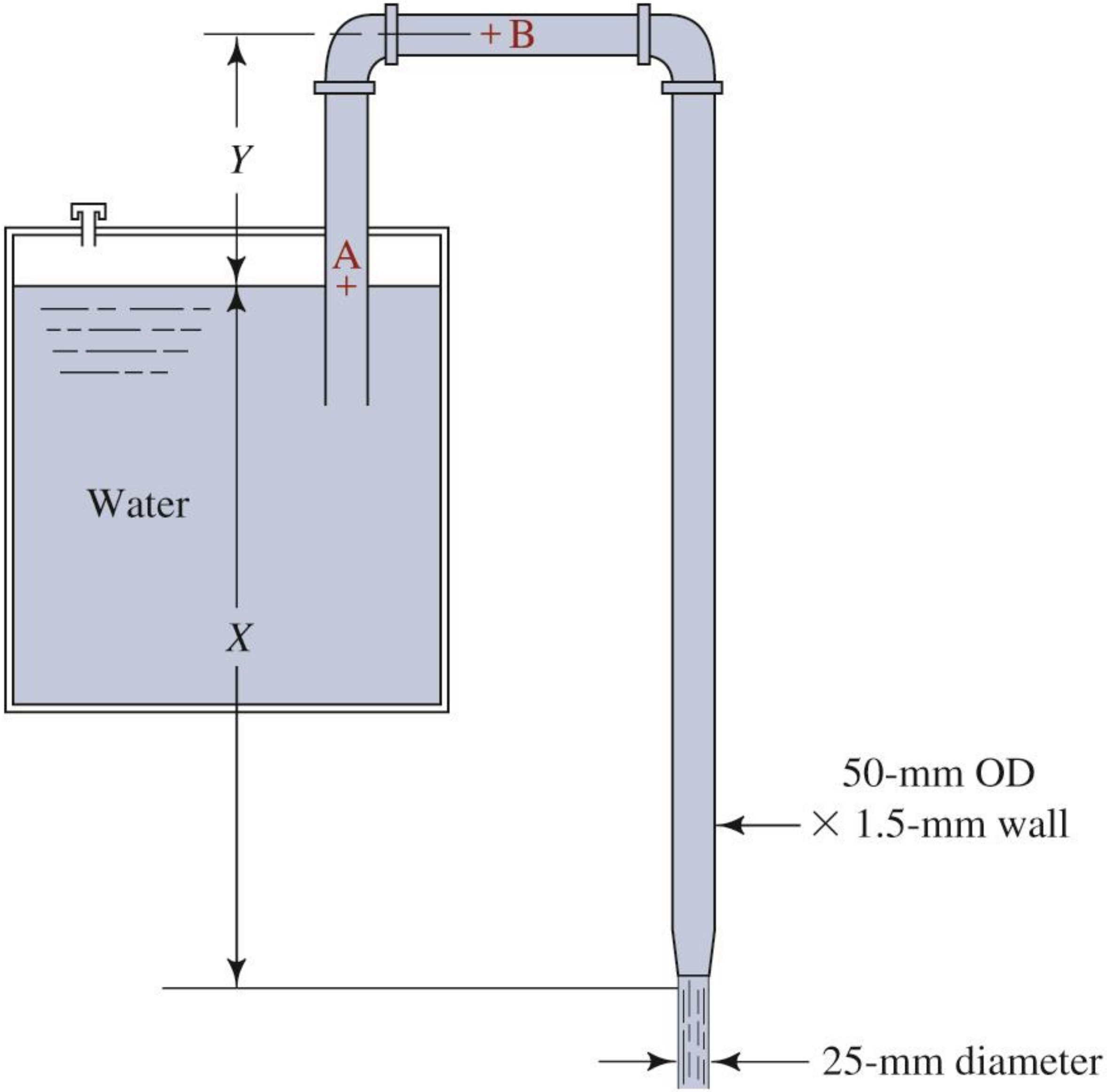


Pearson

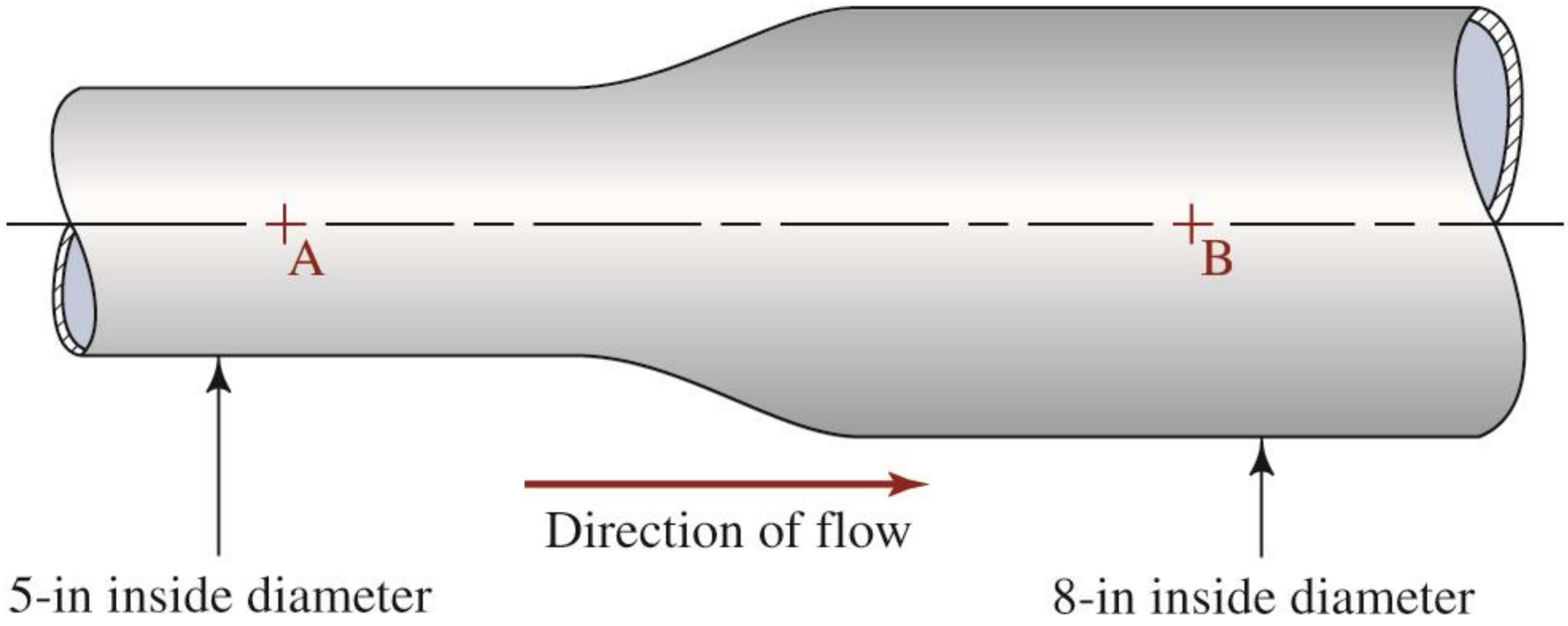
Nozzle for Problem 6.63



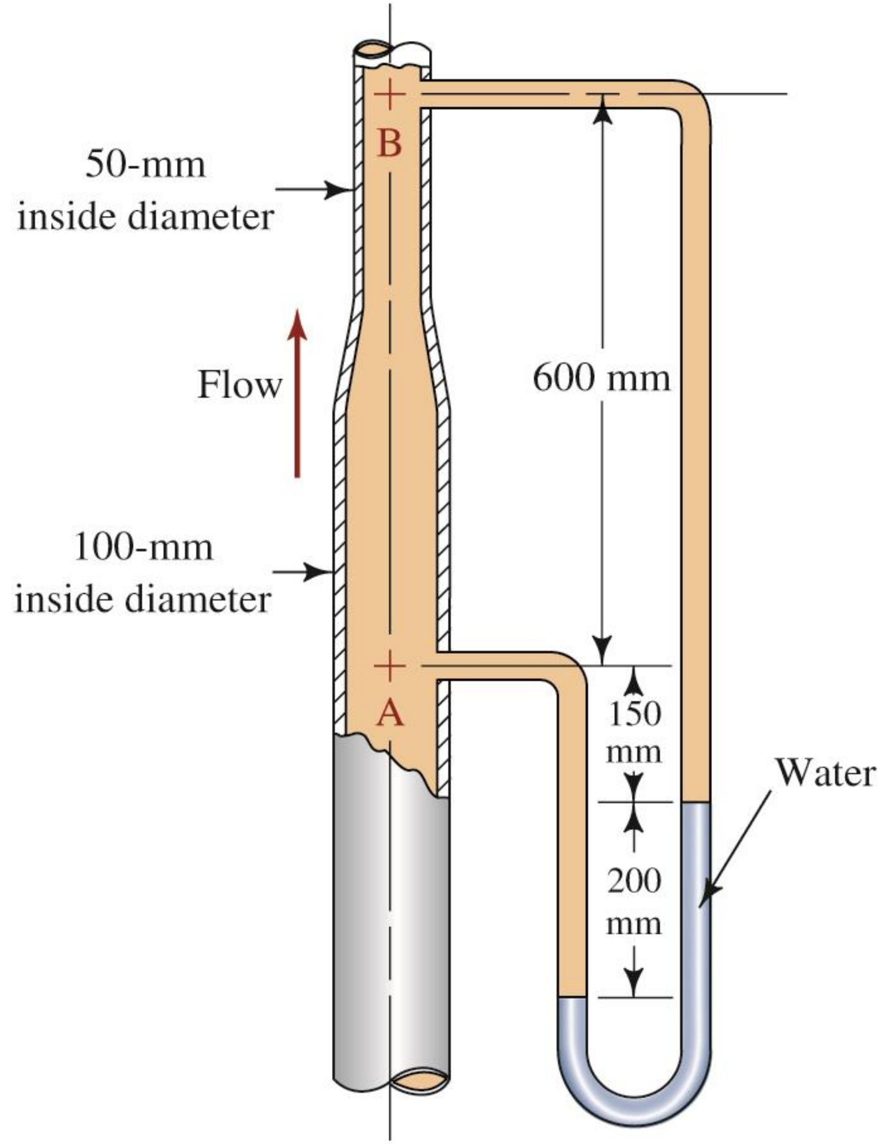
Siphon for Problems 6.69, 6.70, and 6.71



Fabricated enlargement for Problem 6.74



Reducer with manometer for Problem 6.77



Fabricated reducer for Problem 6.81